Behaviour of Precast Reinforced Concrete Slabs in Steel-Concrete Composite Bridge Decks with Bolted Shear Connectors

by

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A thesis submitted for the fulfilment of the requirements for the degree of

Master of Engineering

School of Civil and Environmental Engineering

Faculty of Engineering and Information Technology

University of Technology Sydney

2014

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Sydney, February 2014

ACKNOWLAGEMENTS

This thesis would not have been completed without the guidance, advice and support of a number of individuals whose contribution I would gratefully like to acknowledge. I would specially like to express my gratitude to my supervisors, Professor Bijan Samali and Dr Hamid Valipour.

I would also like to convey my thanks to University of Technology Sydney (UTS) Civil Engineering Laboratories staff, specially the laboratories manager Mr Rami Haddad, senior project engineer Mr Peter Brown and technical officer Mr David Dicker who kindly helped me in project experimental stages.

Furthermore, I am obliged to many of my colleagues and friends who assisted me during my studies. Special thanks must go to my dear friends and co-researchers, Mr Masoud Moradi for his unfailing assistance and support in this research work.

Lastly, I would like to extend my love and gratitude to my dearest family for their support and encouragement. I want to sincerely thank them from the bottom of my heart and acknowledge that without them none of this could have happened and I was not able to achieve most of the things I have in my life.

Hereby, I would like to dedicate this thesis to my family for being such great supports in my life.

LIST OF PUBLICATIONS BASED ON THIS THESIS

Journal Articles

Rajabi, A., Valipour, H., Samali, B. & Foster, S. 2014, 'Effect of Attenuation Function on the Efficiency and Accuracy of Nonlocal 1D Reinforced Concrete Frame Elements', *Computers and Concrete an International Journal* (Under publication).

Conference Papers

Rajabi, A., Valipour, H., Samali, B. & Foster, S. 2012, 'Application of externally post-tensioned FRP bars for strengthening reinforced concrete members', *22nd Australian Conference on the Mechanics of Structures and Materials*, Sydney, Australia, December 2012 in From materials to structures.

ABSTRACT

Due to ease of fabrication and maintenance and speed of construction, precast prefabricated composite deck slabs have gained huge popularity all around the globe. The precast prefabricated structural systems do not require the costly in-situ formworks. Accordingly, the precast prefabricated structural systems can reduce the cost of labour and improve the safety and speed of construction. In addition, the prefabricated composite structures can significantly facilitate application of external reinforcement in lieu of conventional internal steel bars. The reinforced concrete (RC) structures, in general, suffer maintenance and repair difficulties, as internal reinforcements in reinforced concrete (RC) structures are susceptible to corrosion that can be typically accelerated by chloride and other corrosive material ingress. Once the corrosion occurs, reinforcement starts to expand inside the concrete and that in turn causes concrete cracking and spalling. Accordingly, the reinforced concrete member cannot perform its structural role properly. Second generation bridge deck slabs, namely steel-free deck slabs, in which conventional embedded reinforcements are replaced by external reinforcements have proved to be efficient in mitigating the problems associated with corrosion of reinforcing steel bars..

The steel-free deck slabs rely on development of arching action to withstand the load. The inherent arching action in longitudinally restrained reinforced concrete members was realised about fifty years ago, however, the beneficial effects of arching action has not been recognised by most of the existing reinforced concrete design standards yet. So far only **Northern Island** Standard, DRD, NI (1990), and **Canadian** code, OHBD (1992) takes account of the enhancing effect of arching action in design practice. This intrinsic capacity of laterally restrained RC structures helps the flexural reinforced concrete members to show loading capacity far in excess of flexural resistance predicted by the conventional formulas.

Apart from corrosion of reinforcing steel bars, the existing steel-concrete composite deck slabs cannot be repaired and rehabilitated conveniently and without the interruption to the traffic. Although many studies have been conducted examining a wide range of composite deck systems, lack of a practical precast prefabricated steel-concrete deck slab that allow for easy replacement of concrete slabs in case of

deterioration is apparent. The restrained steel-free concrete deck provides a practical solution to the corrosion of reinforcement by removing the internal steel bars and replacing them with external steel straps. However, in the meshless slabs proposed by them, the future repair and replacement of concrete slab cannot be conducted easily without a major interruption to the traffic.

To take advantage of the intrinsic characteristic of precast prefabricated deck slabs and to overcome the issues associated with corrosion of internal steel bars in RC bridge decks subject to corrosive environment, a novel steel-concrete deck with precast prefabricated concrete slabs is proposed and examined in this study. The results of experimental tests on precast prefabricated slabs with high strength bolts are presented and FE numerical simulation are carried out using ATENA 2D. The novelty of this research project lies in the application of high strength steel bolts for connecting the concrete slabs to steel girders. The high strength bolts are pre-tensioned with a special amount of tensile force induced in them by a torque meter wrench. This new steel-concrete composite deck has two main advantages; firstly, there is no requirement as to design and assemble formworks for constructing cast-in-situ concrete slabs and hence the construction of deck is much faster. Secondly, the high strength bolts can be opened and the precast slab can be easily released and replaced if required. This advantage allows for easy repair and maintenance of the concrete deck slab without causing significant interruption to the traffic during repair and rehabilitation.

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NOTATIONS

The symbols used in this thesis, including their definitions, are listed below.

A	Cross-sectional area of a rectangular concrete section
A_s	Cross-sectional area of reinforcement
A_s'	Cross-sectional area of compressive reinforcement
b	Width of a rectangular cross-section (width of slab)
c	Depth of neutral axis
C	Membrane force
C_c	Compressive force carried by concrete
C_s	Compressive force carried by tensile
d	Effective depth (the distance from the extreme fibre to the centroid of the tensile steels)
D	Diameter of high strength bolt
d_b	Diameter of steel reinforcement
d_1	Half of the arching depth
d'	Distance from the extreme compressive fibre to the centroid of the compression steels
e	Distance from neutral axis
E	Modulus of elasticity of steel reinforcement
E_c	Modulus of elasticity of concrete
f_c	Compressive strength of concrete – stress in concrete
f_c'	Characteristic compressive (cylinder) strength of concrete
E_{tot}	The total area under the load-deflection diagram up to the failure load (total energy)
E_{el}	The elastic energy
$E_{0.75pu}$	The area under the load-deflection diagram up to 0.75% the ultimate load.

f_{cu}	Compressive (cube) strength of concrete
f_{cyl}	Compressive (cylinder) strength of concrete
F_t	Post tensioning force induced in high strength bolt
f_u	Specified ultimate strength of steel reinforcement
f_y	Specified yield strength of steel reinforcement
h	Overall height of a rectangular cross-section
h_a	Height of the arch in three-hinged arch theory
h_1	Distance between membrane force at hogging and sagging
I_{10}	Energy ductility index
k	The ratio of the outward movement of the support to elastic shortening of the beam
k	Lateral stiffness in a laterally restrained RC member
K_b	Equivalent stiffness of support beam
K_d	Stiffness of diaphragm and slab
K_r	Combined stiffness of restraint
l	RC member's span length
L	RC member's span length
L_e	Half of span length in elastically restrained arch
L_r	Half of span length in rigidly restrained arch
M_a	Arching moment of resistance
M_{ar}	Arching moment of resistance of rigidly of rigidly restrained slab strip
M_{bal}	Balanced moment of resistance
M_r	Moment ratio (non-dimensional)
m_u	Sagging moment in a yielded section
m'_u	Hogging moment in a yielded section
M_b	Sagging moment in a yielded section

M_{-b}	Hogging moment in a yielded section
n_u	Difference between compressive and tensile forces in a yielded section
P	Applied load
P_a	Predicted ultimate arching capacity
P_b	Predicted ultimate flexural capacity
P_j	Johansen's loads (i.e. flexural capacity using yield line analysis)
P_m	Load due to compressive membrane action
P_p	Predicted ultimate capacity under Park's method
P_{test}	Maximum total load on the slab
P_{vf}	Flexural punching strength
P_{vs}	Shear punching strength
R	McDowell's non-dimensional parameter (elastic deformation)
t	Thickness of slab
T	Tensile force carried by tensile reinforcement
T_b	Torque applied by wrench in high strength bolt
Q_e	Effective reinforcement ratio at principal section
w	Load⁄(unit area carried by arching action)
w	Deflection under the point load
ε_{av}	Average axial strain in a section
ε_0	Concrete compressive plastic strain
ε_u	Concrete maximum compressive strain
ξ	Axial strain
κ	Beam/column curvature
ε	Strain
ε_c	Plastic strain of idealised elastic-plastic concrete

φ	Width of circular patch load
ρ	Longitudinal tension reinforcement ratio in a section (A_s/bd)
ρ_a	Effective arching reinforcement ratio at principal section
ρ_e	Effective reinforcement ratio at principal section
μ	Ductility index (general definition)
$\mu_\emptyset$	Ductility index in term of curvature
μ_θ	Ductility index in term of rotation
μ_Δ	Ductility index in term of deflection
μ_E	Energy ductility index
$\emptyset$	Curvature
$\emptyset_u$	Ultimate curvature
$\emptyset_y$	Yielding curvature
θ	Rotation
θ_y	Rotation at yielding
θ_u	Rotation at ultimate load
β_1	Ratio of depth of rectangular stress block, a, to depth to neutral axis, c
δ	Deflection under the load point
Δ	Deflection at centre of structure member
Δ_e	Mid-span elastic deformation
Δ_u	Ultimate deflection
Δ_p	Mid-span plastic deformation
Δ_y	Yielding deflection